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L. Mynott

LEANNE MYNOTT
TEAM LEADER EXAMINATION
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James – Copy of patent stuff + Disc

Electrically operated tuning forks with novel coaxial coil geometry

1 An electrically driven tuning fork or resonant vibrating cantilever is designed with a coaxial coil, the aim being to increase packing density so as to achieve a smaller overall diameter than existing designs.
The design differs from previous arrangements in that the magnetic field produced by current in the coil is longitudinal rather than transverse, and results in mutual repulsion between the tines even in the absence of any other magnetically active material. Further refinement is possible which uses a more complete magnetic circuit than existing designs.
The winding of a larger coil along almost the full length of the tines leads to applications to fibre scanners with proportionally larger magnetic force and deflection than is possible with standard designs.

2 The diagram shows how the coaxial drive coil allows two complete magnetic circuits to be formed which contain the full length of each tine in series with the external magnetic material and the air gap at the free end. Current through the coil causes an attractive force across the air gap between tine and the external material as well as mutual repulsion between the tines.
The design is versatile in that depending on the need for miniaturisation the external magnetic return path can be omitted to obtain a smaller overall diameter, or part of the space saved can be used to add more turns to the winding.

3 The design need not be symmetrical and there are advantages in a design which is made as asymmetrical as possible, where almost all of the vibrational energy, and deflection, is taken up by a single tine. By a suitable mounting at the built-in end, so as to reduce unnecessary damping, it is possible to avoid the need to carefully match the individual resonant frequencies associated with each tine.* This need for matching in present designs is a tedious step if attachment of, for example, an optical fibre disturbs the operation of the balanced vibrational mode.
A further advantage of asymmetrical operation is that tine and fibre deflection can be markedly increased to the extent that with relatively small overhang a fibre tip can be scanned over the full diameter available.

4 There may be insufficient space, due to restriction of the external diameter, for a return magnetic circuit back to the built-in end. In this case additional driving force can be obtained by including high permeability material beyond the end of the tines. Two strips are added, to which the ends of the tines are attracted when the coil is activated. The process involves magnetism induced in the strips by the fringe field of the coil together with the magnetism of the tines.

5 For efficient operation care must be taken to provide an appropriate drive current. In the absence of any residual or steady magnetic field the force on the tines is in only one direction. The current in the coil, regardless of direction, produces mutual repulsion of the tines or in the case of the complete magnetic circuit an additional force involving attraction across the air gap to the external magnetic material. Under these circumstances a sinusoidal current is not appropriate, especially if magnetic saturation is approached. The driving force peaks twice per electrical cycle and returns to zero for only a very short proportion of the time, resulting in very poor efficiency.

* If however the stiffness of the heavier tine is increased in proportion to its mass then perfect balance can be obtained. Piezoelectric feed back from the base and laser pulse ablation can automate the balancing process.

Instead a square wave pulse of 50% duty cycle produces an optimum drive force even under conditions of magnetic saturation. There is the added advantage that the electrical frequency is equal to the mechanical vibrational frequency.

6 When maximum frequency of operation is required for a given length it is advantageous to taper the width of the tine toward the free end. Although a factor of four increase is possible for a tine which sharply decreases at the halfway point, a uniform or linear taper is more practical and has a more useful deflection curve as a function of length from the built-in end. The operating frequency can be almost doubled by this procedure.

7 To obtain maximum driving force and also increase the mass of the fixed tine in the asymmetrical design, the thickness of the fixed tine can be made to conform to the deflection of the vibrating tine at maximum deflection. The maximum thickness at the built-in end is also convenient for secure attachment of the vibrating tine.

8 The use of a single dominant tine for deflection results in a straight-through geometry well adapted to fibre attachment. At the rest position the entire fibre is quite straight with easy access at the built-in end and line of sight through the coil interior. This configuration also avoids any problems with additional fibre bend loss due to high curvature which can occur at the base of a normal tuning fork when a fibre is threaded around onto the inside surface of a tine.

9 Although a solenoid winding of a few layers is sufficient to provide adequate driving force in most cases, it is possible to take advantage of the small deflection at the built-in end by providing more layers in that region. Depending on tine width and the maximum deflection needed, the number of layers is progressively reduced towards the free end of the tine(s).
In the same way it is possible to employ non-circular cross-section to accommodate tine deflection. This may be an advantage when the slow scan may involve moving the whole assembly within a larger circular cylinder.

10 Permanent magnets may be incorporated in a variety of ways to improve efficiency, especially if the ultimate in miniaturisation is not required. A cylindrical magnet, cut longitudinally if necessary to avoid eddy current losses, can be placed around the assembly and polarised in the axial direction. The tines are then pulled apart slightly in the static position, and this force is modulated by the current in the solenoid. In this case sinusoidal current can be used without any frequency-doubling effect.
Alternately small axially magnetised magnets can be installed at the built-in end in series with the return magnetic path outside the coil.

G.R. 25/3/99

Diagrams for Patent Drawn by James Rudge

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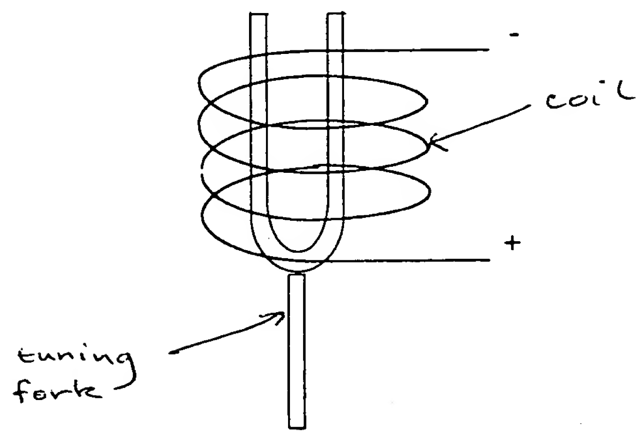

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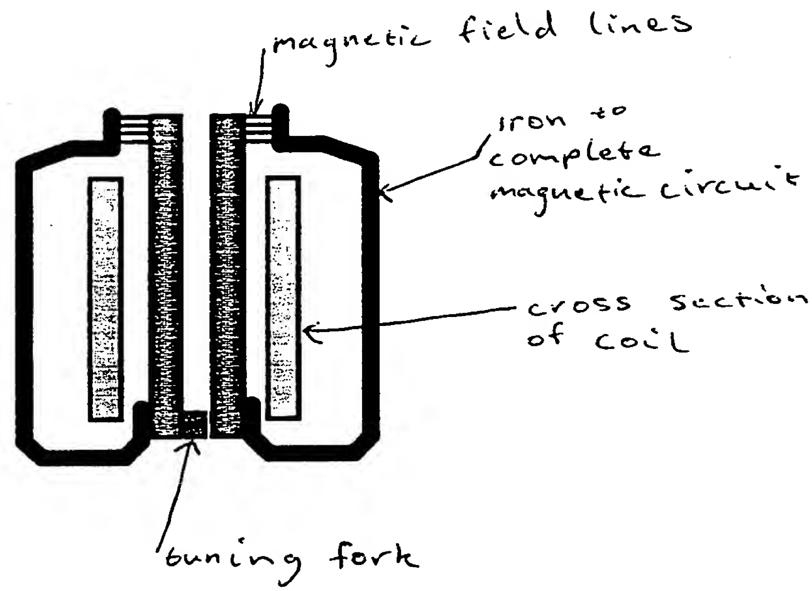

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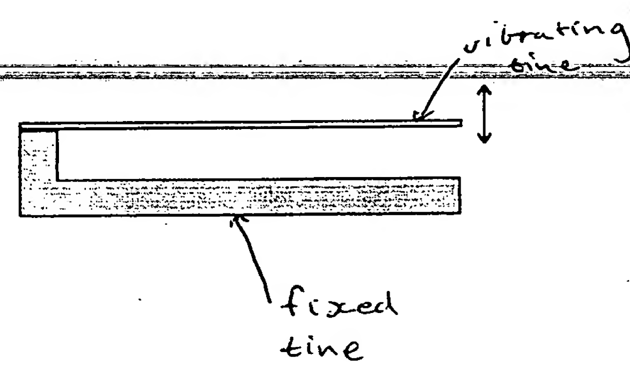

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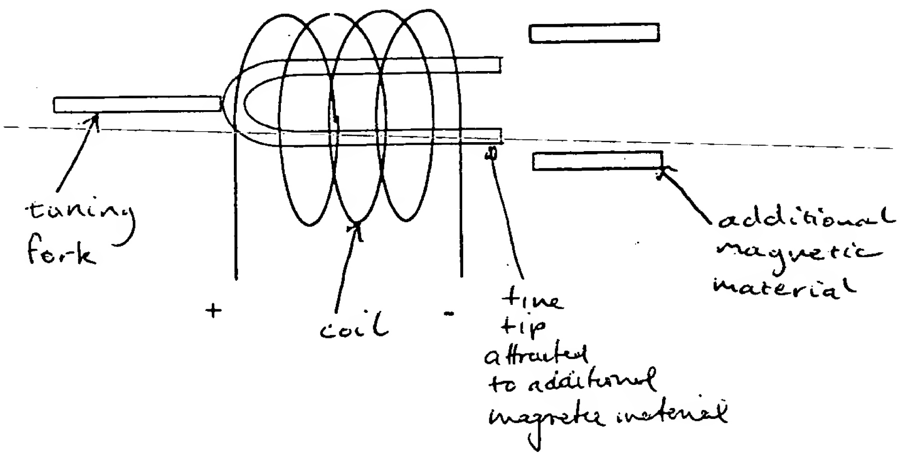

Profile of Tine

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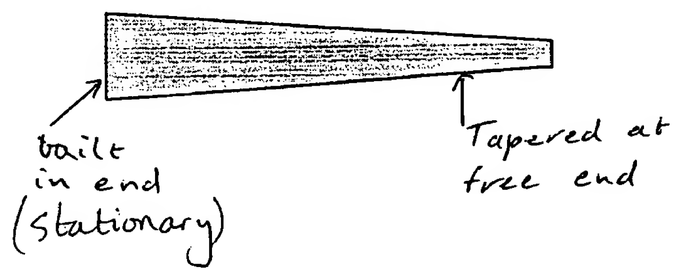

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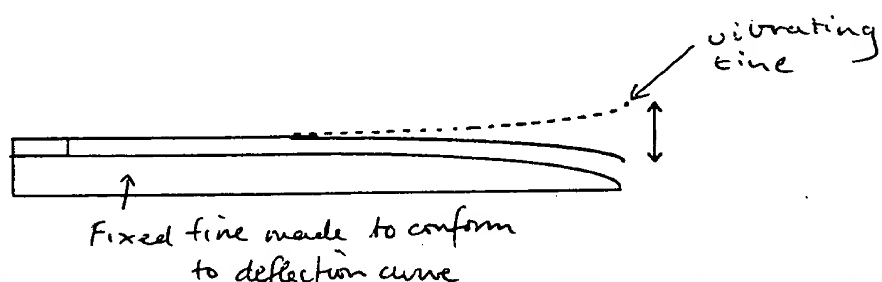

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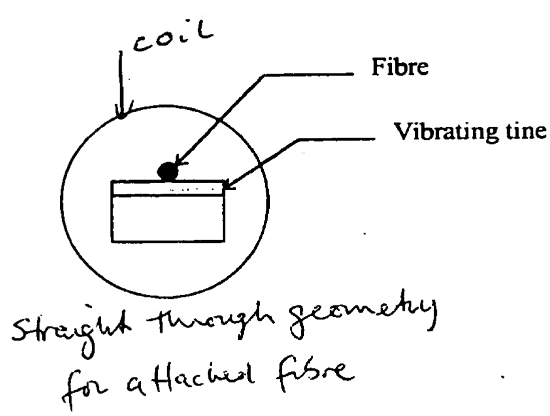

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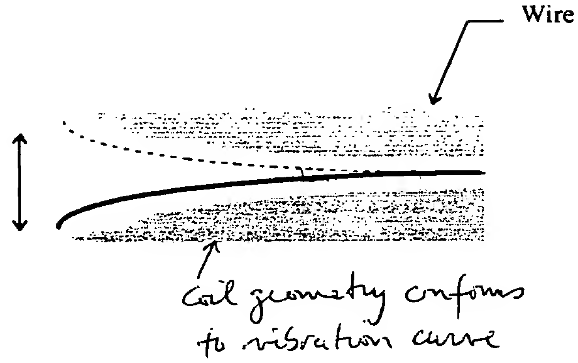

Permanent magnetic Bias

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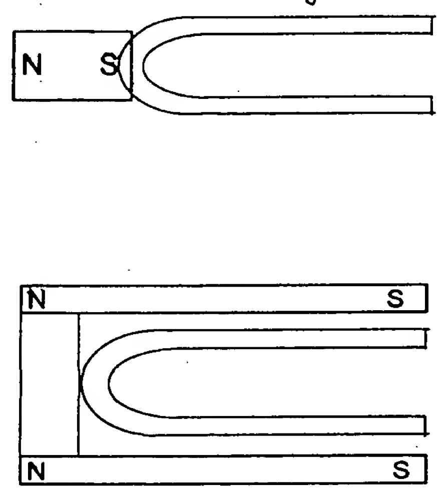

possible forms of permanent magnet bias